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The Value of Moisture-Resistant Containers in Vegetable Seed Packaging

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THE VALUE OF

MOISTURE-RESISTANT CONTAINERS

IN VEGETABLE SEED PACKAGING[1]

by JAMES F. HARRINGTON

VEGETABLE SEED PACKAGING has been undergoing major changes, among them a rapid shift toward the use of moistureproof or moisture-resistant containers. This shift has been brought about through the research of Barton (1935, 1939),[2] Boswell *et al.* (1940), and the Associated Seed Growers, Inc. (1954), which repeatedly demonstrated that sufficiently dried seeds will maintain germination and vigor much longer than seeds of higher moisture contents. However, little information has been available on the relative value of different types of containers as barriers against penetration of water vapor.

This bulletin reports research findings on the value of moisture-resistant containers for preserving high germination and vigor of vegetable seeds, and on several related factors that affect seed storage in moisture-resistant containers.

Seven experiments are reported in this bulletin. The main findings were these:

The data confirmed previous experiments that the higher the storage temperature the faster the loss in germination; also the higher the seed moisture the faster the loss in germination. The findings substantiated the rule of thumb that each 1% drop in moisture doubles the life of the seed.

Among various containers tested, the tin can was found moistureproof if properly sealed. If tin cans are considered to be 100% resistant to moisture-vapor transmission, then three other types of containers can also be so regarded. These are aluminum cans (but proper sealing seemed to be more difficult), hermetically sealed glass jars, and pouches made of aluminum foil (.0035-inch thick laminated to mylar or polyethylene, with or without surface paper lamination).

Containers 80 to 90% resistant to moisture-vapor penetration and satisfactory as moisture-resistant seed containers include aluminized polyester pouches, multiwall paper bags with inner aluminium lamination and properly sealed, and high-density polyethylene of 3 mil or more in thickness.

Containers showing fair resistance to moisture-vapor transmission include asphalt-laminated multiwall paper bags, polyethylene-laminated paper bags, and friction-top tin cans.

Containers showing no resistance to moisture-vapor transmission were paper and cloth bags.

Polyethylene was found more resistant to moisture-vapor transmission at lower than at higher temperatures.

When the oxygen and CO_2 content of

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[1] Submitted for publication May, 1962.

[2] References refer to sources listed in Literature Cited, page 23.

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the atmosphere around seeds in sealed storage was analyzed, it was found that there was a drop in O_2 concentration which was greater than the build-up in CO_2 concentration. This drop in O_2 concentration and build-up of CO_2 concentration was faster in warmer storage and with seeds of higher-moisture content, which indicated greater respiration. Yet, onion seed showed excellent germination after the storage when O_2 had dropped to as low as 4% and the CO_2 concentration had increased to as high as 13%. Although containers in which the seed had died always contained an atmosphere low in O_2 and high in CO_2, this change in atmosphere was not necessarily correlated with seed deterioration.

Old seeds or seeds declining in germination were less resistant to adverse storage conditions than high-germinating, freshly harvested seed.

Onion seeds properly dried for storage, treated with the fungicide Arasan or the combination fungicide-insecticide Delsan, were not adversely affected by these treatments.

If seeds dried for safe storage in sealed containers were kinds which develop hard seed coats, it was found that acid scarification to eliminate the hard seededness was unsatisfactory. Abrasive scarification was satisfactory for okra, flowering morning glory, and garden peas. Neither method of scarification was satisfactory for sweet peas, pole beans, and lima beans.

It is evident that other important qualities for containers include ruggedness, ease of sealing and handling, low cost, and resistance to insect and rodent penetration.

A more detailed discussion of the seven experiments follows.

EXPERIMENT II

INVESTIGATION OF EIGHT TYPES OF CONTAINERS FOR MOISTURE TRANSMISSION AND GERMINATION OF SEEDS STORED IN THEM

TYPE OF CONTAINERS

The following containers were tested to package the seed:

1. Paper—multiwall kraft paper bags (4-ply 50 lb kraft).
2. Paper-poly—multiwall kraft paper bags, with a layer of poly-ethylene laminated to the inner surface of the inner ply (3-ply 50 lb kraft + 1-ply 1/10 lb PE on 50 lb kraft).
3. Crepe-double poly—multiwall kraft crepe paper bags, with two layers of polyethylene (2-ply 1/10 lb PE on 70 lb crepe kraft + 2-ply 50 lb kraft).
4. Paper-poly + poly bag—same as 2, with a 3-mil high-density polyethylene liner in each bag.
5. Poly bag—polyethylene 6-mil high-density bags.
6. Paper-foil—multiwall kraft paper bags, with aluminum foil laminated with polyethylene to inner ply (3-ply 50 lb kraft + 1-ply 1/10 lb PE, .0035 foil, 1/10 PE on 50 lb kraft).
7. Foil pouch—aluminum foil pouch (paper 1/10 lb PE, .0035 foil, 1/10 lb PE).
8. Tin can—tin cans, enamel lined.

Container 1 was sewn shut; containers 2, 3, 4, and 6 were sewn and heat-sealed with a polyethylene tape over the stitching; containers 5 and 7 were heat-sealed; and container 8 was sealed in a can-closing machine.

SEEDS TESTED

Six kinds of seed were used: cabbage, carrot, lettuce, onion, muskmelon, and tomato. Each kind of seed was divided into three lots, and the moisture content was adjusted either by drying in a dehumidifying drier at 100°F or by misting with the proper amount of water, to obtain high, medium, and low moisture levels. Table 1 gives the moisture contents and the germination percentages at the start of the experiment.

STORAGE CONDITIONS

Four storage conditions differing in temperature and/or relative humidity (RH) were used to test the containers:

Desert	100°F	12% RH
Tropic	100°F	90% RH
Frigid	0°F	50% RH
Temperate	50°–90°F	10%–90% RH

The temperate storage was a common storage subject to the daily and seasonal fluctuations in temperature and RH.

With the tin cans and the foil pouches, a different container was used for each sub-lot of seed, so that any change in seed moisture was the result of moisture penetration through the container. With the other containers the sub-lots of each kind of seed were placed in cloth bags and combined to make six sub-lots in each container, because they were too large to use as individual containers. The moisture content of the different kinds of seed in a container changed slightly as they came into equilibrium with each other. This was independent of the diffusion of moisture in or out of the bag. The lettuce and onion seed gained approximately 0.7% moisture, the tomato seed, approximately 0.2%; the carrot and muskmelon seed lost approximately 0.4%; and the cabbage seed, approximately 0.6%. Thus, to some extent the moisture level originally intended was changed in these six containers. In the tin cans and the foil pouches each kind of seed maintained the original moisture content.

TABLE 1. MOISTURE CONTENT AND GERMINATION OF EACH SEED LOT AT START OF EXPERIMENT

Moisture level	Cabbage	Carrot	Lettuce	Muskmelon	Onion	Tomato
	Per cent moisture in seed					
High	8.57	10.37	6.87	9.04	9.98	9.84
Medium	7.50	8.01	5.93	6.80	8.73	7.60
Low	5.20	5.73	4.04	4.42	7.06	4.48
	Per cent germination					
High	86	80	88	91	84	97
Medium	87	82	89	95	85	98
Low	87	83	86	92	87	98

TIME OF STORAGE

Containers were removed 1, 3, 6, and 12 months after the start of storage.

Thus the treatments consisted of 8 containers × 6 kinds of seed × 3 moisture levels × 4 storages × 4 dates of removal. This equaled 2,304 individual sub-lots or treatments tested.

Preliminary findings of Experiment I were published by Harrington, 1960.

MOISTURE TRANSMISSION

The moisture transmission was determined in this experiment by measuring the change in moisture content of the seeds. In figure 1 the changes of seed moisture in four representative containers are shown for each of the four storage climates. In the tropic storage of 100°F and 90% RH, there was the greatest absolute increase in seed moisture, with the seeds in the paper bag showing the most. On the other hand, in the desert storage of 100°F and only 12% RH, there was a rapid loss of moisture from the seed in the paper bag, intermediate loss in the paper-poly + poly bag and the paper-foil containers, and no measurable loss from the tin can or the foil pouch. Under temperate and frigid storage the paper bag was the only container that allowed an appreciable transmission of moisture vapor. Apparently the polyethylene is more resistant to moisture transmission at lower temperatures than it is at higher temperatures.

To give a complete picture of the relative moisture transmission, it was assumed that the paper bag allowed 100%

FIGURE 1. *Change in moisture content of vegetable seeds stored in four different containers under temperate, frigid, tropic, or desert storage for 1, 3, 6, and 12 months*

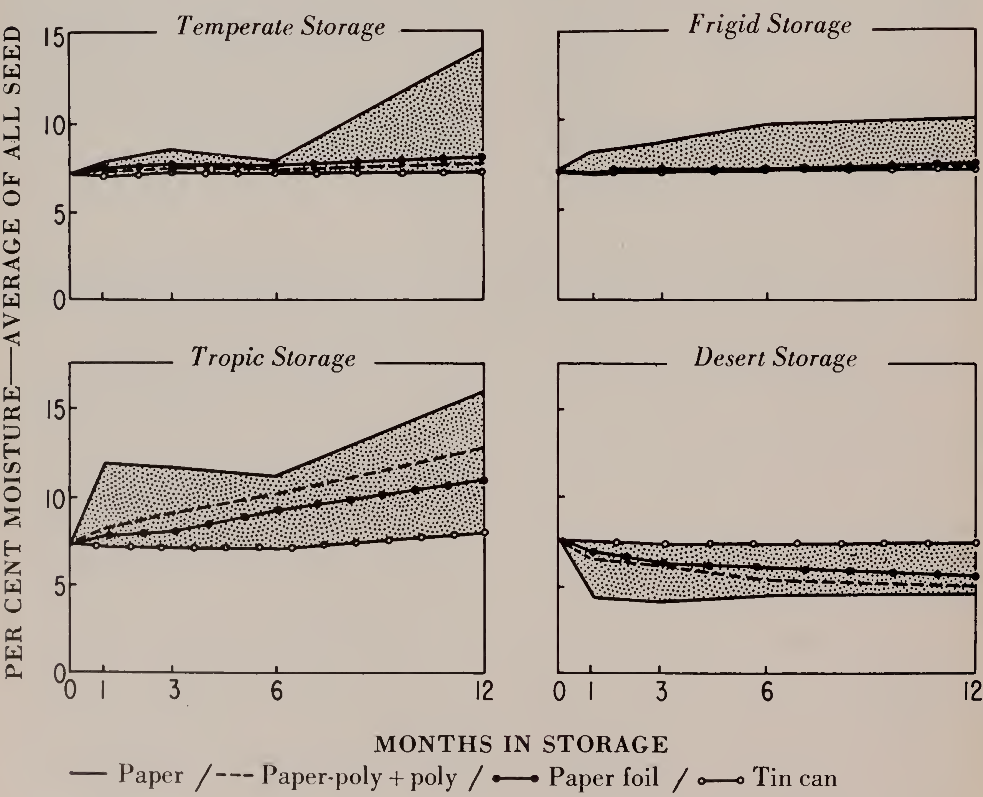

TABLE 2. AVERAGE MOISTURE TRANSMISSION THROUGH EACH CONTAINER AS A PERCENTAGE OF TRANSMISSION THROUGH PAPER UNDER THE SAME CONDITIONS

Container	Storage				
	Tropic	Desert	Temperate	Frigid	Average
	Per cent				
Paper	100	100	100	100	100
Paper-poly	114	99	47	25	71
Crepe-double poly	99	91	35	21	61
Paper-poly + poly bag	51	57	7	−2	28
Poly bag	33	33	16	5	22
Paper-foil	30	38	18	3	22
Foil pouch	1	7	−12	−2	−2
Tin can	0	4	−11	−7	−4

Container × storage L.S.D. 99:1 = 23.4%.
Container average L.S.D. 99:1 = 11.7%.

transmission. The moisture transmission through the other containers after 1, 3, 6, and 12 months was calculated as a percentage of the moisture transmission through the paper bag, and the four figures for each container under each storage condition were averaged. The data are presented in table 2.

The containers fall into four groups as to resistance to moisture penetration.

Excellent. The seed in the tin can and the foil pouch show no significant change in moisture content under any climatic condition tested. Thus these two containers, if properly sealed, are moistureproof.

Good. The containers having high-density polyethylene of 3 mil or greater thickness (poly bag and paper-poly + poly bag) and the foil-laminated bag are resistant to moisture transmission at 100°F and seem to be almost moistureproof at temperatures of around 70°F and lower.

Fair. The very thin layer of polyethylene on the paper-poly and crepe-double poly has little or no resistance to moisture-vapor transmission at 100°F and only fair resistance at the lower temperatures.

Poor. The paper bag showed no resistance to moisture-vapor transmission under any storage condition tested.

GERMINATION

The purpose of using moistureproof or moisture-resistant packages for seeds is to maintain their germination as long and as high as possible. The above data show a wide range of moisture resistance from the moistureproof tin can and foil pouch to the moisture-permeable paper bag. The data in figure 2 show the effect of storage up to 12 months in these containers. Moreover, the loss in germination is a function of the moisture content of the seed and the length of storage. A particular container was effective in maintaining high germination only so long as it maintained low seed moisture.

Figure 2 shows the curve of deterioration in germination ability with increase in moisture of each kind of seed following 1, 3, 6, and 12 months of storage. The area below the crosshatching on each

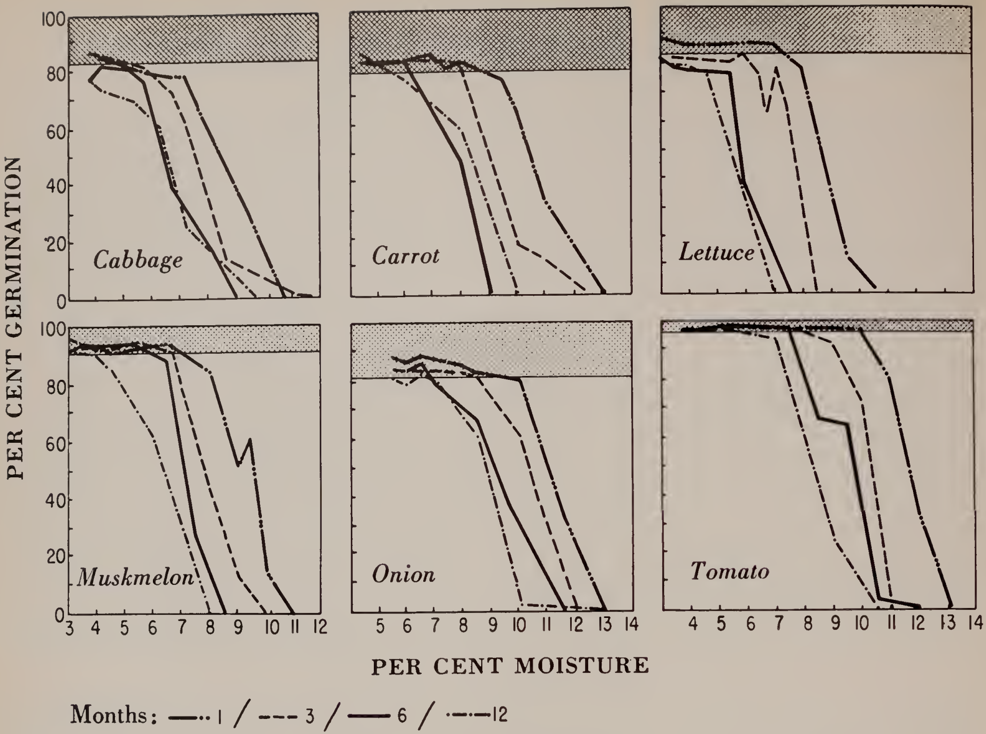

FIGURE 2. *Germination percentages of vegetable seed as a function of their moisture content when stored at 100°F for 1, 3, 6, and 12 months*

graph represents the region where a significant drop in germination has occurred. The chi-square test by analysis of variance shows that there is no significant change in germination in any of the seeds stored in the frigid storage even after 12 months of storage. The average germination and the standard error for each kind of seed are as follows:

Cabbage	87.8 ± 4.57
Carrot	81.9 ± 3.94
Lettuce	88.8 ± 4.97
Muskmelon	93.8 ± 2.77
Onion	85.5 ± 3.95
Tomato	97.8 ± 1.56

Therefore, the straight line below the crosshatching of the chart for each kind of seed is the line of the mean germination in frigid storage less the standard error of that mean.

Lettuce declined in germination at lower moisture contents than the other kinds of seeds, and tomato at higher moisture contents. However, if the moisture content was 10% or higher, the seeds of all kinds tested were dead or very low in vitality after 12 months. Data in figure 2 show that carrot seed of lower moisture content declined in germination more rapidly at six months than at 12 months. This cannot be explained. Table 3 gives the moisture contents at which a significant decline in germination was apparent after 1, 3, 6, or 12 months for each kind of seed. The 12-month value for cabbage was interpolated. Lettuce was anomalous: by three months of storage it had dropped to a plateau in the lower moisture range that was significantly below the germination of the seed from the frigid storage. Yet

TABLE 3. SEED-MOISTURE CONTENT AT WHICH A SIGNIFICANT DROP IN GERMINATION OCCURRED AFTER 1, 3, 6, AND 12 MONTHS OF STORAGE AT 100°F

Seed	Months of storage			
	1	3	6	12
	Per cent seed moisture			
Cabbage	5.4	5.0	3.9	3.4
Carrot	8.8	8.3	6.4	5.8
Lettuce	7.3	6.1	5.6	4.7
Muskmelon	7.0	6.5	5.6	4.2
Onion	9.2	8.1	6.9	6.6
Tomato	9.2	7.5	7.4	5.9
Average	7.8	6.9	6.0	5.1

there was still a sharp break where germination declines seriously for each storage time. The moisture content at this sharp breaking point is used in table 3 for lettuce.

At 100°F, the rule of thumb that a 1% drop in moisture doubles the life of the seed was reasonably substantiated by the average moisture content at which the six kinds of seed showed a significant decline in germination. At 3 months this average was 6.9%; at 6 months it was 6.0%, or a drop of 0.9%; and at 12 months it was 5.1%, another drop of 0.9%.

EXPERIMENT III THREE TYPES OF MOISTURE-RESISTANT CONTAINERS TESTED FOR LOW-MOISTURE SEED IN HIGH-HUMIDITY STORAGE

TYPES OF CONTAINERS

Since Experiment I had established the hermetically sealed can (tin can) as acceptable standard for judging the desirability of other containers for packaging low-moisture seed, two other containers were studied for comparison under conditions of high-humidity storage. They were a heat-sealable aluminized polyester pouch, and a triple-seal, friction-top can such as is used for paints. The cloth bag was used as a check.

Onion seed, variety Excel, moisture content, 7.2% (dried at 90°F in a dehumidifying drier), germination 82%.

was packaged in the following containers on July 14, 1960:

1. Tin can—baby-food size.

2. Paint can—pint-size with triple-friction seal lid.

3. Pouch—aluminized polyester.

4. Cloth bags.

Approximately one ounce of seed was put in each container. Two lidded aluminum buckets were used to hold the containers. Five containers of each kind were placed in each lidded bucket. The containers were set on a wire screen over water in the bottom of the bucket. Wetted blotting paper was placed under the lid. The blotting paper was rewet as needed to keep the humidity in the buckets as near saturation as possible. The buckets were transferred daily except Saturdays and Sundays between 77°F for 16 hours and 32°F for 8 hours.

VAPOR-PENETRATION STUDIES

Water vapor can penetrate a container in two ways: by diffusion through the container walls if they allow vapor transmission; through cracks or poor seals, even through minute holes if there is an expansion and contraction of the internal atmosphere because of temperature changes. To test for both methods of vapor penetration, the above four kinds of containers filled with seed were placed under high-humidity conditions and the temperature was alternated between 77°F and 32°F daily.

SAMPLING

One of each kind of container was removed from each bucket 2, 4, 8, 16, and 32 weeks after the beginning of the experiment.

Carbon dioxide, oxygen, and nitrogen content of the atmosphere in each container was determined by gas chromatography of a sample obtained by puncturing the container through a rubber gasket sealed on the side and immediately withdrawing the sample in a hypodermic syringe.

A sample of the seed in each container was taken immediately on opening the container and was tested in duplicate for moisture content.

Another sample of seed was taken for germination tests made according to official methods (Justice, 1952).

MOISTURE CONTENT AND GERMINATION

As shown in table 4, under the short time (32 weeks) and relatively cool temperature average of this experiment (77°F for 16 hours and 32°F for 8 hours for an average of 62°F), seed germination did not decline in any of the moisture-resistant containers. In the cloth bags the moisture content of the seed rose to 59% and the germination dropped to 0%.

There was no change in moisture content of the seed in the tin cans. The average moisture content was 7.09 ± 0.03. Seed moisture in aluminized pouches had risen significantly in 16 weeks, and after 32 weeks was 0.6%–0.7% higher than at the start. In paint cans moisture content increased significantly in 4 weeks. The apparent decrease in moisture from the 16- to the 32-week averages was most likely caused by variations in the tightness of the seals between the lids and the cans.

RESPIRATION

The respiration of the seed in the tin cans, measured by CO_2 increase, was low but constant, approximately doubling each time storage time doubled. Seed respiration in the pouches, measured by CO_2 increased, was more rapid. This can be explained by the fact that the moisture content of the seeds increased with storage time. The CO_2 content of the atmosphere in the paint cans increased to about 1% and then remained roughly constant, presumably because CO_2 diffused out through the same cracks by which the

TABLE 4. COMPOSITION OF ATMOSPHERE, MOISTURE CONTENT OF SEED, AND GERMINATION OF ONION SEED STORED IN FOUR TYPES OF CONTAINERS FOR 2, 4, 8, 16, AND 32 WEEKS UNDER CONDITIONS OF HIGH RH AND 77°–32° F DAILY ALTERNATING TEMPERATURE

Storage time	Container			
	Tin can	Pouch	Paint can	Cloth bag
Weeks	Per cent CO_2			
2	0.1	...	0.1	..
4	0.2	0.1	0.2	..
8	0.3	0.3	1.4	..
16	0.6	1.0	1.3	..
32	1.2	2.1	1.0	..
	Per cent O_2			
2	20.6	....	20.9	..
4	19.9	19.8	20.4	..
8	21.0	21.4	21.0	..
16	20.0	19.2	19.4	..
32	18.4	15.9	18.6	..
	Per cent moisture in seed			
0	7.2	7.2	7.2	7.2
2	7.0	7.0	7.2	16.5
4	7.0	7.1	7.4	22.9
8	7.1	7.2	7.6	30.3
16	7.2	7.5	12.4	40.3
32	7.1	7.8	9.4	59.0
	Per cent germination			
0	82	82	82	82
2	83	84	80	81
4	80	82	80	72
8	83	80	81	65
16	80	80	79	43
32	81	83	86	0

moisture vapor entered. The daily alternation of temperatures caused condensation of moisture on the different containers, and two of the paint cans rusted completely through. The data from these cans are not included.

COMPARISON OF PERFORMANCE

This experiment again confirmed that the hermetically sealed *tin can* allows no moisture transmission and is still the standard by which to judge other containers as a means for storing seed.

The paint can did not provide a completely desirable barrier, as the seed moisture content rose from 7.2% to 12.4% in 16 weeks and CO_2 diffused from the can. However, even after 32 weeks at the relatively cool average temperature of 62°F, the germination of the seed had not declined.

The aluminized polyester pouch was nearly as effective as the tin can, even though there was an increase of about 0.6% moisture in the seed under these high-humidity conditions. If onion seed of 6.5% moisture is packaged in this container, properly sealed, there should be no decline in germination in three years under natural climatic conditions even in the southeastern United States.

EXPERIMENT III — EFFECT OF SCARIFICATION ON HARD-COATED SEED STORED IN MOISTUREPROOF CONTAINERS

THE PROBLEM OF HARD SEED

Many seeds develop hard seeds if dried to moisture contents satisfactory for safe storage in sealed containers.

Hard seeds are not dead but do not germinate immediately when planted in moist soil; where rapid germination is essential for good crop yield, hard seeds must be avoided. This can be done by scarification of the seeds, either by abrasion or acid treatment. Both of these methods, however, may reduce the storage life of the seeds.

Drying seeds below natural dryness and storing them in moisture-proof containers will prolong the storage life of the seeds but may counteract the effect of scarification. This experiment was designed to investigate this problem.

PREPARATION OF SEEDS

Seven kinds of seeds were used to compare the effect of scarification on the germination and hard-seed percentage at three moisture contents after storage for a year. The original germination, hard-seed percentage, and moisture content of the seeds tested are shown in table 5.

Abrasive scarification was done by nicking the seedcoat of each seed with a file. Acid scarification of the seeds was accomplished by dipping them in concentrated sulfuric acid, rinsing thoroughly with water and drying them quickly. The duration of the acid treatment was determined in a preliminary experiment, using 2-, 5-, 15-, and 60-minute treatments. Fifteen minutes appeared to be most satisfactory for every kind except morning glory. The seeds did not appear pitted and germination immediately after treatment was normal; hard seeds were completely or almost completely eliminated. In the case of morning glory, one-minute treatments of acid were given; treatment even as short as two minutes caused all seeds to rot.

All seeds were individually inspected, and those showing a visible crack were eliminated. One-third of each kind of seed was scarified, one-third acid treated, and one-third was not treated. The lots were further subdivided and stored in two-quart Mason jars. One set of jars contained no desiccant; another, freshly

TABLE 5. ORIGINAL GERMINATION, HARD-SEED PERCENTAGE, AND MOISTURE CONTENT OF SEEDS USED IN THE SCARIFICATION EXPERIMENT

Seed	Variety	At start of experiment		
		Germination	Hard seed	Moisture content
		Per cent		
Lima Bean	U.C. Breeding Line	83	3	9.3
Pole Bean	Lazy Wife	91	4	12.8
Runner Bean	Scarlet Runner	100	0	9.4
Garden Pea	Little Marvel	75	0	8.6
Sweet Pea	Floribunda Mixed	78	10	9.9
Okra	Clemson Spineless	79	0	8.8
Morning Glory	Heavenly Blue	60.5	34	8.8

dried silica gel; and a third, phosphorous pentoxide. Some jars were stored at 95°F and others at room temperature, 68° to 77°F. Enough seed of each kind to provide two 100-seed germination tests and two 2-gram samples for moisture tests were wrapped in cheesecloth and placed in each jar. Only 50 seeds each were used for the two germination tests of runner beans. Germination and moisture tests on each lot of seed were made after one year of storage.

MOISTURE CONTENT

The moisture content of the seeds in the sealed containers without a desiccant was essentially unchanged by the end of the experiment except for the pole beans. These, with a higher initial moisture content of 12.8%, declined as the different kinds of seeds came into equilibrium with each other in each container. The quantity of P_2O_5 placed in the containers did not bring the moisture content of the seeds down quite as low as in the containers with silica gel.

EFFECT ON BEANS

Table 6 summarizes the principal results of this experiment. At moisture contents below 5.0% there were no hard seeds in the Scarlet Runner variety of runner beans. Thus, it would appear that hard seeds are not a problem with this variety and no scarification seems to be necessary. However, a white-seeded variety such as White Dutch Runner might show hard seeds, since white-seeded snap and lima-bean varieties show a greater tendency toward hard-seededness than colored-seeded varieties. The germination data indicate that the H_2SO_4 treatment was injurious to runner beans. In contrast to the pole and lima beans, drying to below 5.0% moisture did not affect germination of runner beans.

The pole bean was the only kind tested that showed a drop in germination in the undesiccated treatments. This was probably due to the high original moisture in these seeds, too high for safe storage. Drying to 6% moisture and below seriously reduced the germination of lima-

TABLE 6. MOISTURE CONTENT, GERMINATION, AND HARD-SEED PERCENTAGE OF SEVEN KINDS OF SEED STORED FOR ONE YEAR AT ROOM TEMPERATURE OR 95°F IN SEALED CONTAINERS OVER NO DESICCANT, P_2O_5, OR SILICA GEL

Seed	Desiccant								
	None	P_2O_5	Sil. gel	None	P_2O_5	Sil. gel	None	P_2O_5	Sil. gel
	Moisture content			Germination			Hard seeds		
	Per cent								
Lima Bean									
Room temp., untreated	9.9	6.3	5.0	87	39	26	1	12	22
95°F, untreated	9.8	6.0	4.8	88	30	12	0	43	30
95°F, H_2SO_4	10.0	6.0	4.6	91	37	29	0	0	0
95°F, filed	9.7	5.5	4.6	85	12	66	0	1	0
Pole Bean									
Room temp., untreated	9.8	6.2	5.0	61	17	12	8	57	56
95°F, untreated	9.7	6.1	4.7	69	13	4	8	76	68
95°F, H_2SO_4	9.9	5.6	4.5	60	39	9	0	1	0
95°F, filed	9.4	5.4	4.5	31	29	25	0	0	0
Runner Bean									
Room temp., untreated	10.3	6.1	5.0	99	99	95	0	0	0
95°F, untreated	9.6	6.1	4.7	93	96	91	0	0	0
95°F, H_2SO_4	10.0	5.8	4.6	85	98	70	0	0	0
95°F, filed	9.5	5.5	4.6	98	95	96	0	0	0
Garden Pea									
Room temp., untreated	9.1	5.4	4.3	89	92	88	5	3	6
95°F, untreated	9.0	5.4	4.3	81	89	84	0	4	7
95°F, H_2SO_4	9.0	5.2	4.2	93	90	93	0	0	1
95°F, filed	8.5	4.7	4.2	96	90	82	0	0	0
Sweet Pea									
Room temp., untreated	10.3	6.1	4.9	90	72	62	4	16	26
95°F, untreated	10.1	6.2	4.7	78	69	48	8	19	19
95°F, H_2SO_4	9.9	5.8	4.6	77	54	55	1	4	4
95°F, filed	9.6	5.4	4.6	60	44	15	0	0	0
Okra									
Room temp., untreated	9.5	5.4	4.4	74	80	60	1	4	14
95°F, untreated	8.8	5.4	4.1	63	74	54	2	4	18
95°F, H_2SO_4	9.0	5.0	4.2	90	78	56	0	3	22
95°F, filed	8.8	5.0	4.0	87	88	60	0	1	1
Morning Glory									
Room temp., untreated	8.8	5.5	4.5	77	70	69	21	29	29
95°F, untreated	8.6	5.5	4.3	93	71	68	4	25	29
95°F, H_2SO_4	8.8	5.2	3.9	95	74	74	5	24	26
95°F, filed	8.5	5.0	3.9	98	97	96	0	1	0

bean seeds even when the hard seed content was included. The scarification by either H_2SO_4 or filing eliminated the hard-seededness, but also caused a serious decline in germination of both lima and pole-bean seeds at moisture contents of 6% or lower. Therefore, it is not safe to dry these seeds to 6% for long-time storage. From the data it appears that a range of 9 to 10% moisture is safe.

PEAS

On the other hand, drying to 4% moisture did not affect the germination of garden-pea seeds, and neither did scarification by either H_2SO_4 or filing. Scarification eliminated the hard seeds, although the percentage was not high at the beginning. Little Marvel, however, is not one of the pea varieties most subject to hard-seededness.

Scarification by either method seriously reduced sweet-pea germination at all moisture contents and, therefore, does not appear to be a desirable practice with this kind of seed.

OKRA AND MORNING GLORY

Filing, or abrasive scarification, successfully eliminated hard seeds of both okra and morning glory without loss in germination. Acid scarification was not successful with either of these kinds of seed—as, in fact, it was unsatisfactory for all seeds tested. It is possible that high-temperature storage alone decreased the hard-seed content of morning-glory seed of about 8% moisture content without any decline in germination.

EXPERIMENT IV MOISTUREPROOF STORAGE OF SEED TREATED WITH FUNGICIDE AND INSECTICIDE, AND OF LOW-GERMINATING OR OLD SEED

TESTS ON ONION SEED

Seedmen who plan to store seeds in moistureproof or moisture-resistant packages need to know the effects of fungicides and insecticides on longevity and the role of temperature and moisture on maintaining longevity of low-germinating or old seed. Onion seed, among the vegetable seeds, loses its viability most quickly and, for this reason, lends itself to a study of viability deterioration.

The following three lots of onion seed were obtained:

Excel Lot 22607, 1956 crop, germinating 92% in November, 1956.

Excel Lot 22217, 1956 crop, germinating 83% in August, 1956.

Sweet Spanish "A" Lot 15730, 1953 crop, germinating 90% in November, 1954; 90% in August, 1954; 90% in January, 1955; 82% in February, 1956; and 75% in August, 1956.

DIVISION INTO LOTS

Part of the first lot was slurry-treated with Arasan, an organic fungicide, and another part was slurry-treated with Delsan, which is Arasan plus the insecticide Dieldrin. Thus there were five lots of seed in all, as shown on the next page.

TABLE 7. AVERAGE MOISTURE CONTENT OF ONION SEED IN SEALED CONTAINERS AT THE START OF EXPERIMENT AND AFTER 3 YEARS

Seed condition	Seed moisture					
	High		Medium		Low	
	Start	End	Start	End	Start	End
	Per cent seed moisture					
High germination	7.6	7.5	7.2	7.3	6.2	6.2
Low germination	7.8	7.9	7.2	7.3	6.6	6.5
Old seed	8.2	8.2	7.0	7.0	6.1	6.1
Arasan treated	8.4	8.3	6.8	6.9	5.9	5.9
Delsan treated	8.4	8.4	6.9	7.2	6.1	6.1
Average	8.1	8.1	7.0	7.1	6.2	6.2

1. High-germinating new crop seed, untreated.

2. Low-germinating new crop seed, untreated.

3. Old seed breaking over from high to low germination, untreated.

4. High-germinating new crop seed, Arasan treated.

5. High-germinating new crop seed, Delsan treated.

Each lot was dried to three moisture levels. The high-moisture level was approximately 8%; the medium, 7%; and the low, 6%. Other workers, including Boswell *et al.* (1940), have found that 6% is proper for long-time storage, with 7% and 8% adequate for storage for shorter periods. During the three years of the experiment there was no change in moisture content of the seed in the cans at any temperature or with any treatment, as can be seen in table 7.

The seeds of the 15 lots were canned in baby-food cans and stored in water-jacketed incubators at 32°, 59°, 68°, 77°, 86°, and 95°F. The incubators had a variation of ± 1.0°F, depending on position of the sample in the incubator, and ± 2.0°F fluctuation in temperature when properly adjusted.

There were 10 cans for each of the five treatments, at each of the three moisture contents, at each of the six temperatures, or a total of 900 cans. Cans were removed after 1, 2, 3, 5, 8, 12, 18, 24, 30, and 36 months.

GERMINATION RESULTS

The germination results are shown in tables 8 and 9. In table 8 the germination figures are presented for the original high-germinating seed, untreated, treated with Arasan, and treated with Delsan. There was no deterioration of high-vigor onion seed of 8% moisture or lower when stored at 86°F or lower for a period of three years, nor of onion seed of 6% moisture or lower when stored at 95°F or lower. Treatment of the seed with Arasan or Delsan had no effect under these conditions. However, the seed of 7% or 8% moisture stored for three years at 95°F significantly declined in germination, and the treated seed declined in germination faster under these

conditions than did the untreated seed. Practically speaking, there was almost no difference between the untreated and treated seed.

In table 9 the germination figures are presented for the untreated, originally high-germinating seed (these figures are also in table 8), the originally lower-germinating seed, and the seed that was old at the beginning of the experiment.

At 32°F, regardless of the original quality of the seed, there was no decline in germination during the three years of storage of seed of 8% moisture or lower. At 77°F only one condition had caused a significant decline in germination: the old seed of 8% moisture stored for three years. At 86°F only the old seed had significantly declined in germination, but even the old seed of 6% moisture declined significantly in only one year. At 95°F the decline of germination in the old seed was much more rapid, to 0% germination at the higher-moistures and the longer-storage times. At this high-storage temperature there were significant drops in germination after three years of both the high- and lower-germinating lots if the moisture content was 7% or 8%.

It appears, then, that old onion seed that is beginning to decline rapidly in

TABLE 8. GERMINATION AFTER 0, 1, 2, AND 3 YEARS OF THE ORIGINALLY HIGH-GERMINATING ONION SEED, UNTREATED, TREATED WITH ARASAN, OR TREATED WITH DELSAN

Storage temp.	Time in years	Untreated			Arasan-treated			Delsan-treated		
		Seed moisture								
		6%	7%	8%	6%	7%	8%	6%	7%	8%
		Per cent germination								
	0	94	94	94	94	94	94	92	92	92
32°F.	1	91	91	88	93	93	92	92	89	92
	2	86	93	94	94	96	88	94	93	98
	3	90	90	91	90	90	90	91	89	90
77°F.	1	89	94	96	88	92	92	88	92	94
	2	95	93	89	97	94	93	91	89	90
	3	90	88	88	94	92	90	93	92	91
86°F.	1	91	92	92	94	92	91	98	95	92
	2	90	79	93	90	92	93	83	98	91
	3	86	85	90	92	91	88	88	92	82
95°F.	1	85	94	87	92	91	87	92	90	86
	2	93	89	86	93	92	78	94	92	82
	3	90	71*	40*	88	60*	0*	90	60*	0*
		LSD 99:1 – 17.72			LSD 99:1 – 26.21			LSD 99:1 – 26.18		

* Germinations significantly less than at the start.

TABLE 9. GERMINATION AFTER 0, 1, 2, AND 3 YEARS OF NEW ONION SEED OF HIGH GERMINATION, LOWER GERMINATION, AND OLD SEED AT THE START OF THE EXPERIMENT

Storage temp.	Time in years	High original germination			Lower original germination			Old seed		
		Seed moisture								
		6%	7%	8%	6%	7%	8%	6%	7%	8%
		Per cent germination								
	0	94	94	94	82	82	82	69	69	69
32°F.	1	91	91	88	80	82	84	60	59	62
	2	86	93	94	66	82	84	64	73	73
	3	90	90	91	78	70	81	63	53	65
77°F.	1	89	94	96	76	74	82	59	58	57
	2	95	93	89	81	76	78	53	56	67
	3	90	88	88	83	72	80	66	55	42*
86°F.	1	91	92	92	82	80	84	51*	56	39*
	2	90	79	93	69	62	69	35*	47*	26*
	3	86	85	90	70	70	62	38*	38*	5†
95°F.	1	85	94	87	77	72	70	58	41*	17†
	2	93	89	86	80	66	52*	49*	30†	0†
	3	90	71*	40*	71	36*	0†	14*	0†	0†
		LSD 99:1 − 17.72			LSD 99:1 − 23.29			LSD 99:1 − 17.53		

* Germinations significantly less than at the start.
† Germinations of 0% or not significantly different from 0%.

germination in open storage is much more affected by adverse temperature or seed moisture than new seed. Further, the treatment of high-germinating seed with Arasan or Delsan has little or no adverse effect on onion seed of 8% moisture or lower stored in sealed containers.

GAS ANALYSIS

The onion seeds were canned in February, 1957 in baby food cans, each holding slightly over two ounces of seed (about 71 grams per can). Each can contained a volume of 140 cc, of which the seeds occupied approximately 67 cc (onion seed sp. gr. = 1.17) and the atmosphere 73 cc.

The cans were sampled by gluing a piece of gum rubber on the side, driving a small nail through the rubber and can side, and quickly taking out a sample of the internal atmosphere with a hypodermic needle.

The Aerograph gas chromatograph method was used. Cans from all treatments were analyzed for O_2, CO_2, and N_2. The results shown in table 10 are the averages of all five treatments.

The results show the sharp decline in

O_2 percentage, even at 32°F. However, the CO_2 percentage did not increase as fast as the O_2 percentage decreased, resulting in a negative pressure in the can. It is possible that some of the oxygen was used up in oxidation of the tin or iron of the can itself, but this is unlikely, as the can and lid were both enameled. However, the enamel may have oxidized to some extent and the seed coats of the onion seeds which were dead may have oxidized, or there may have been adsorption of oxygen by the seed. It is also possible that there was considerable anaerobic respiration.

The higher the temperature, as long as there was no decline in germination, the greater the amount of oxygen used and the greater the release of CO_2. This is, no doubt, due to the greater rate of respiration at the higher temperatures. But at 95°F, where there was a sharp decline in germination after three years of storage, the oxygen used was not as great as at 86°F and the CO_2 produced was greater. In fact, with the 8% moisture seed at 95°F, the O_2 plus CO_2 percentage of 23.8% exceeded the total of these two gases in the original atmosphere. Perhaps on death of the cells the CO_2 and O_2 are released from the cells of the seed to the atmosphere of the container.

TABLE 10. GAS ANALYSIS OF ATMOSPHERE AROUND ONION SEED STORED IN SEALED CONTAINERS FOR THREE YEARS AS COMPARED TO THE SEED MOISTURE AND SEED GERMINATION

Storage temp.	Seed moisture	O_2	CO_2	N_2	Seed germination
	Per cent				
32°F.	6	14.4	0.8	84.8	83
	7	14.5	0.7	84.8	78
	8	10.0	0.8	89.2	84
77°F.	6	7.2	3.8	89.0	85
	7	7.9	4.9	88.2	80
	8	5.3	7.6	87.1	78
86°F.	6	4.9	13.6	82.5	75
	7	4.6	11.2	84.2	75
	8	3.6	7.8	88.6	66
95°F.	6	3.8	14.2	82.0	71
	7	6.3	15.6	78.1	45
	8	10.8	13.0	76.2	8

EXPERIMENT V

ALUMINUM CAN INVESTIGATED AS SEED CONTAINER

ONION SEED TESTED

The aluminum can, a container not included in the previous experiments has the advantage of not rusting. To test it as a seed container, onion seed of two moisture contents (7.3% and 9.3%) germinating 75.5% was sealed in aluminum cans on February 17, 1957, and stored at 86°F or 95°F until November 21, 1960, a period of 3 years and 9 months. Gas samples of the atmosphere in the sealed cans were analyzed by gas chromatography at the end of the experiment. The moisture content of the seed and its germination were also determined. There were originally three cans for each moisture level at each temperature, but gas analysis and careful examination of the cans revealed that the one can in each temperature containing the low-moisture seed had been poorly sealed. The data for these cans are reported separately.

GERMINATION AND MOISTURE CONTENT

The results (see table 11) indicate that 9.3% moisture in the onion seed was too high for 3¾ years' storage at 86°F or 95°F, and that a moisture content of 7.3% was too high for storage at 95°F for the same period, but was satisfactory at 86°F. The results also indicate that it may be more difficult to obtain a good seal with an aluminum can than with a tin can. As germination goes down, O_2 is depleted; but germination does not always decline when the atmospheric O_2 declines. Also, 95°F appears to be injurious to onion seed of moisture contents of 7% or higher.

TABLE 11. GERMINATION AND MOISTURE CONTENT OF ONION SEEDS STORED 3¾ YEARS IN ALUMINUM CANS, AND THE CO_2 AND O_2 CONTENT OF THE ATMOSPHERE IN THE CANS

Storage temperature	Original seed moisture	Can seal	After 3¾ years' storage: Germination	Seed moisture	Can atmosphere: CO_2	O_2
	Per cent		Per cent			
86°F......	7.3	Good	76	7.3	5.5	8.1
	7.3	Poor	64	7.2	0.1	21.0
	9.3	Good	1	9.3	13.3	2.8
95°F......	7.3	Good	3	7.3	3.0	6.4
	7.3	Poor	3	7.0	1.0	19.4
	9.3	Good	0	9.4	18.7	1.8

EXPERIMENT VII

RELATIONSHIP BETWEEN CO_2 PRODUCED AND GERMINATION OF SEEDS SEALED IN TIN CANS

TEST WITH EGGPLANT SEED

Eggplant seed was dried to several moisture levels, sealed in tin cans, and stored from July, 1958 to July, 1960 at 77°F, common storage, or 32°F. At the conclusion of the expermient the gas atmosphere was analyzed for CO_2, and the seed germination and seed moisture were determined. The results are presented in table 12. The results are the averages from two or three cans.

There appears to be a relationship between the CO_2 produced and the loss in germination, with an amount of 0.1 mg CO_2 per gram dry weight of seed in two years being related to a decline in germination and an amount of around 1.0 mg CO_2 being related to death of all the seed. As the temperature increased, the rate of CO_2 produced and the decline in germination are both hastened, but the relationship between CO_2 produced and loss in germination is the same at each temperature.

TABLE 12. CO_2 PRODUCED (EXPRESSED AS MG CO_2 PER GM DRY WEIGHT OF SEED), GERMINATION, AND MOISTURE CONTENT OF EGGPLANT SEED STORED FOR TWO YEARS IN A SEALED CONTAINER AT THREE DIFFERENT TEMPERATURES

Seed moisture range	77°F storage			Common storage			32°F storage		
	CO_2 prod.	Germination	Seed moisture	CO_2 prod.	Germination	Seed moisture	CO_2 prod.	Germination	Seed moisture
	Per cent								
11.0–11.2	3.32	0	11.2	.51	6	11.0	.01	76	11.1
8.5– 9.1	.15	38	8.8	.10	52	8.8	.01	75	9.0
6.9– 7.3	.11	65	7.1	.06	61	7.1	.01	78	7.2
4.2– 4.3	.06	75	4.3	.03	69	4.2	.01	73	4.2
4.0– 4.2	.01	78	4.1	.01	78	4.1	.01	76	4.2

EXPERIMENT VIII ADDITIONAL INVESTIGATIONS OF CONTAINERS FOR MOISTURE TRANSMISSION AND GERMINATION OF STORED SEED

TYPES OF CONTAINERS

This experiment, similar to Experiment I, tested five types of containers for the storage of onion seed. The storage climates were the same as in Experiment I: temperate, tropic, desert, and frigid. The onion seed lots were placed in cloth bags, and each cloth bag was placed into the following types of containers:

1. Cotton bags.
2. Multiwall paper bags.
3. Asphalt laminated multiwall paper bags.
4. Polyethylene laminated multiwall paper bags.
5. Aluminum foil laminated multiwall paper bags.

Thus, numbers 2, 4, and 5 were the same as bags 1, 2, and 6 of Experiment I.

The onion seed was the same as in Experiment V. At the start it contained 7.3% moisture and germinated 75.5%.

The experiment lasted two years, and lots were removed 6, 12, 18, and 24 months after the start, except that no lots were received for the 24-month period from the desert and frigid storages. Results are summarized in table 13.

GERMINATION

Under the desert storage conditions (100°F – 12% RH) the moisture diffused out of all containers except the foil-laminated container, so the onion seed-moisture content reached a sufficiently low level that storage was reasonably satisfactory. However, the moisture content of the seed in the foil-laminated bag remained too high, causing a rapid loss

TABLE 13. GERMINATION OF ONION SEED (ORIGINAL GERMINATION 75.5%) STORED FOR TWO YEARS IN VARIOUS CONTAINERS AND UNDER DIFFERENT CLIMATIC CONDITIONS

Container	Temperate				Tropic				Desert			Frigid		
	Months													
	6	12	18	24	6	12	18	24	6	12	18	6	12	18
	Per cent germination													
Cotton	65	70	71	4	0	0	0	0	78	70	64	28	0	0
Paper	64	66	65	67	0	0	0	0	77	70	59	38	0	0
Asphalt	64	68	84	79	0	0	0	0	76	68	66	72	52	71
Polyethylene	63	67	72	71	0	0	0	0	65	64	60	74	70	73
Foil	72	68	69	70	0	0	0	0	45	6	6	75	74	80

of germination. Thus, with high-moisture seed stored in a moisture-resistant container in the desert, the barrier to moisture movement was a detriment, again emphasizing the need for properly drying the seed before placing it in a moisture-resistant container.

Under frigid storage 0°F – 50 RH) the differences among containers are most clearly shown. At this temperature 7.3% moisture is safe for long-time storage of onions, but with 50% RH the seed gained moisture to 9% or greater if the container was not a moisture barrier. Thus, the seed in the cotton and paper bags rapidly lost viability. In this experiment the foil-laminated multiwall paper bag was best for resistance to moisture penetration, the polyethylene and asphalt laminated multiwall paper bags were both good, and the cotton and paper bags were poor.

Under tropic conditions none of the bags were useful in preventing complete deterioration of the seed of 7% moisture content within six months.

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The seed in *Experiment II* was supplied by the Asgrow Seed Company, in *Experiment IV* by the Ferry-Morse Seed Company. In *Experiment III* the okra, runner bean, morning glory, and sweet pea seeds were furnished by the Fredonia Seed Company, the pea seed by the Ferry-Morse Seed Company, the snap bean seed by the Kellogg Seed Company, and the lima bean seed by Dr. R. W. Allard of the Agronomy Department of the University of California, Davis.

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